



MODIS Science Team Meeting  
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## **MODIS Science Team Meeting Minutes**

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## **July 23, 2002**

Dr. Vincent Salomonson, the MODIS Team Leader, welcomed attendees to the Plenary Sessions of the July 2002 MODIS Science Team Meeting and thanked them all for attending. He indicated that he feels we are as a whole going to be very far along by the fall.

The Terra and Aqua MODIS instruments are working well; Dr. Salomonson said that the characterization of Terra MODIS is excellent and geolocation is going well. The A-side formatter errors are still rising, but have not yet affected the science data. When the science data starts to be affected, a plan is in place to switch to cross-strap the instrument to the B-side formatter. Aqua MODIS is operating well with the exception of Band 6, on which half of the detectors are dead and will have to be substituted for by another Band.

Oceans data Collection 4 reprocessing began June 15, 2002 and will be completed in October 2002. Land and Atmospheres reprocessing will start after the completion of Oceans and run until 2003.

Multidisciplinary data sets are now available on an ftp site and a CD, 5000 of which will be produced and handed out at upcoming conferences. The ftp site is:

[ftp://modis.gsfc.nasa.gov/pub/Data\\_Sets/](ftp://modis.gsfc.nasa.gov/pub/Data_Sets/)

Direct broadcast is going well. MODIS usage in science and applications is growing; e.g. in Rapidfire, NOAA "Bent Pipe," and albedo in models. However, data product access is still a nagging concern. The area of data subsetting needs improvement, particularly on the EDG. He expressed the ideal of creating a user interface that can accommodate, for example, a new graduate student with a two-year-old laptop. Along these lines, there will be a Data Product Access Panel Discussion on July 24, 2002, featuring Dr. Sara Graves, Director of the ITSC, and Dr. Rahul Ramachandran from the University of Alabama, Huntsville. They will present on Data Mining, ESML, and Subsetting.

## **Terra Status**

Dr. Jon Ranson, Terra Project Scientist, announced that all instruments are acquiring science data. The main concern is the MODIS A-side formatter issue – there are about 30 million resets a day. There are plans to cross strap the instrument to the MODIS B-side formatter when the resets start to affect the science data. The ASTER instrument has a SWIR cross-talk problem that may encourage the instrument team to accept a lunar look maneuver; MOPITT is still working on half of its channels; and there are no issues on CERES or MISR.

Terra has been performing a number of inclination-adjust maneuvers to establish a 10:30 am ( $\pm 5$  minutes) equator crossing. Following the fifth maneuver in March 2002, the spacecraft went into a safe hold. Recovery was nominal. The sixth and final maneuver has been postponed until September while Lockheed comes up with

telemetry monitors and prepares recommendations about spacecraft procedures. After this last maneuver, Terra will not have to do any more inclination-adjustment maneuvers for the next few years.

As for recompetition, the RFP concept discussed at the last team meeting appears to be changing to an NASA Research Announcement; there will a joint call for Maintenance and Science. The NRA, prepared by Jim Dodge, is in review at NASA HQ.

Nearly all data products are available at the DAACs. CERES, MOPITT, and MISR still have unreleased products, but most are on schedule. The EOS data information site lists the status of all data products, and can be accessed at <http://eosdatainfo.gsfc.nasa.gov>. Each instrument team should inform the science community about appropriate uses of Beta and Provisional data products via the EOS site. The EOS Science Working Group on Data has been working on issues related to increased processing and data distribution, has been involved in long-term archive discussions, and will soon address data access and usage. ASTER will begin charging for data (Japan already does), and NASA HQ is finalizing the data-charging plan; they anticipate that there will be a ~\$55 per scene charge to get ASTER data from Eros Data Center. CERES has done a good job of getting ERBE-like instantaneous and monthly averages validated since March; and the MOPITT global example of CO dynamics has not yet produced any validated data.

Terra is improving our ability to detect human impacts on climates by identifying indicators that can be distinguished from natural variability. The satellite is getting a lot of play on its ability to detect natural disasters and make observations that improve predictions of climate and weather. In closing, Dr. Ranson announced that the Earth Observatory was nominated for the 2002 Webby Award and won the People's Choice Award, which is a very great honor for a great site.

## **Aqua Status**

Dr. Claire Parkinson, Aqua Project Scientist, began her presentation by saying that the past few months have been very exciting for Aqua. Although there were numerous problems in March and April, by the time of launch, everything was ready, and the launch countdown and launch itself were flawless, with the spacecraft lifting off at the very start of its 10-minute launch window, at 2:55 a.m. on May 4th, 2002. Later in the day, the flawless countdown and launch were followed by a flawless spacecraft separation and flawless deployments of the solar array, the AMSR-E antenna, both CERES instruments, and the X-band antenna.

Parkinson gave highlights of Aqua's early on-orbit progress and showed first-light images from each of the six Earth-observing instruments, then reported on the status of various additional items, including the deep space maneuver (on hold until the coordinated Terra/Aqua plan is finalized), Aqua-related paper submissions (32 papers have been submitted and are in review for the Aqua Special Issue of the IEEE TGARS), AIRS icing (going to take a week to

defrost in August, but still getting nice data), and the Aqua brochure and trading cards (completed and available).

Dr. Parkinson closed by reporting that Aqua is in operation at a 705 km altitude, all instruments are sending back data, all teams have generated first light images, and press releases are in the process of being finished (AMSR-E already done). One of the next press releases will be for the MODIS instrument.

### **Aqua/Terra MODIS Instrument Status**

Dr. Bill Barnes started the Instrument Status presentation by saying that this is the first time that he's had the opportunity to report on the active status of both instruments, instead of only Terra.

There were a few Terra MODIS issues. The first was with the Band 26 de-stripping issue; MCST plans on using Band 5 to de-stripe Band 26, and the algorithm affecting this change will probably be submitted around October of this year. There is also an issue with the time-dependent RVS LUT. The scan mirror is degrading, but the degradation only impacts Bands 8, 9, 10, and 3. The lunar approach did not affect the degradation rate as anticipated, but many of the oscillations normalized out, so the degradation is currently at 7-8%. The L1B software needs to be changed because it isn't following the trend, the problem being mainly with the ocean color bands. They plan to reinitiate in October and plan on changing the a0 value to 0 for PC Bands 33-36. Lastly, the formatter errors are up to over 30 million per day. The software is making it possible to ignore them, but it is still an issue that needs to be resolved. Dr. Barnes said that they have about a month or two before they will have to switch to the other formatter.

As for Aqua MODIS, they have been running a number of calibration and characterization activities on the SD/SDSM, the BB, Ecal, the SRCA, lunar observations, Itwk/Vdet sweeps, nighttime day mode observations, and yaw maneuvers. The thermal leak on Band 7 (frames 1, 2, and 3) is having a much smaller effect on Aqua MODIS than on its Terra counterpart. The PC Bands optical leak occurring on Terra is not present on Aqua, which is good news. Aqua's TEB NEdT looks cleaner than does the one in Terra MODIS, and the SNR looks good as well. The biggest issue present on Aqua MODIS is the Band 6 operability issue. Band 6 is problematic, and at present there are only 9 or 10 working detectors left. We will probably lose more after the next warming cycle. Lastly, geolocation is improving, but at present it is unclear how it will be affected by the last safe hold. Overall, though, the instrument looks quite good.

### **Calibration and Cross-Calibration of MODIS Using Railroad Valley**

Dr. Kurt Thome said that he and the Remote Sensing Group have been using the reflectance-based method in their MODIS calibration efforts. They are measuring surface reflectance at a well-understood test site – Railroad Valley in Nevada – and are comparing the

measurements to those from the MODIS Level 1B radiances. The team is also performing cross-calibrations with ETM+ (LANDSAT7) data. Since the last Science Team Meeting, they have added four reflectance-based data sets, and seven additional sets were affected by cloudy weather and equipment limitations. They have also added one cross-calibration data set and attempted some initial calibrations of Aqua MODIS.

He explained that the group's method is to attempt to characterize the reflectance of the surface, which is extremely flat and fairly uniform. The results from combining the surface measurements with atmospheric data are not too scattered,  $\pm 3\%$ , and they feel that these results will allow a direct calibration of MODIS on Aqua for which there are no accompanying high-resolution sensors. The group has observed preliminarily that Aqua's measurements are different from Terra's. Aqua is far enough from Terra measurements that they feel the need to examine the results more closely and try to figure out what is causing that difference. Otherwise, Dr. Thome said that there is pretty good agreement between MODIS and ETM+. The MODIS measurements compared to other instrument's measurements look pretty encouraging. Additional data sets in the month of August 2002 should allow further understanding of the Aqua results as well as outlier results

### **Direct Broadcast MODIS Atmosphere Products at UW - Madison**

Mr. Liam Gumley announced that over 3000 Terra MODIS passes have been acquired at UW-Madison. Mr. Gumley explained that the IMAPP Goal is to provide freely available, portable, and easy-to-install software for processing raw MODIS and AIRS/AMSU/HSB data. He thanked the Goddard people who developed the operational MODIS L1 codes from which IMAPP is derived.

Mr. Gumley explained that the IMAPP Level 1 Products for Terra MODIS contains L1A, Geolocation, and Calibration data, and uses downlinked ephemeris and attitude data for real-time processing (within 60 minutes of the end of a pass). IMAPP supports a number of operating systems, the only requirement being the HDF v4.1 toolkit. IMAPP includes a script to process L0 data into L1B data, and the calibration algorithm is very close to the latest LUT version. Mr. Gumley continued that Level 2 products released include Cloud Mask, Cloud Top Pressure, and Cloud Phase; meanwhile the Atmosphere Profiles product is in Beta tests; and Ancillary data are available from the SSEC via an anonymous ftp. They have been running the de-stripping algorithm for Band 26 for a month, and have found that it is especially useful for the cloud mask product.

As for Aqua, they are working on the code right now, and will soon have a shared code for L1A, Geolocation, and Calibration, but will eventually require separate Terra and Aqua codes for Calibration. Beta testing is in progress, and they are assessing the impact of

GBAD ephemeris on Geolocation. Level 1 will be available for release in August, and L2 will be available in the fall of 2002.

Mr. Gumley said that the group hopes by August 2002 to release Aqua-compatible IMAPP Level 1 s/w, by September 2002 to release Aqua-compatible IMAPP Level 2 s/w, and by the end of the year to update the Terra Aqua calibration algorithm to v4.0. As for AIRS/AMSU/HSB, they plan to evaluate and test the pre-launch version of Level 1A s/w; by the end of 2002 to obtain the post-launch version of Level 1 suite and to produce Level 1 products in near real-time; by early 2003 to modify Level 1 s/w for inclusion in IMAPP; and by the summer of 2003 to release Level 1 s/w as a part of IMAPP.

## **NPP VIIRS Status**

Dr. Jeffrey Privette explained that the NPOESS Preparatory Project (NPP) is a "bridging mission" that provides for the continuation of measurement series initiated with EOS Terra and Aqua for NASA's global change research, specifically in climate change, the global carbon cycle, and the global water cycle. Further, NPP provides risk-reduction for the NPOESS mission, which will continue those measurements into the indefinite future. Finally, he explained that NPP is a joint program of NASA and the Integrated Program Office (IPO). The mission of NPOESS is fourfold: to provide a national, operational, polar-orbiting environmental capability; to achieve National Performance Review savings by converging DoD and NOAA polar satellite programs; to incorporate new technologies from NASA and others; and to incorporate, where appropriate, international cooperation, specifically from EUMETSAT.

Near the nominal end of the EOS/Terra mission (~2006), there will be a gap until the start of NPOESS, which will be filled by NPP. NPP will include the VIIRS, CRIS, and ATMS sensors, plus perhaps one or two instruments of opportunity. He briefly explained the individual products and which channels will provide them. Dr. Privette explained what led to the design of VIIRS (and its similarity to MODIS) as well as that the purpose of VIIRS is to gather global observations of land, ocean, and atmosphere parameters at high temporal resolution (daily). He noted it uses a rotating telescope design similar to SeaWiFS, and that new baffling has been added around the blackbody and behind the telescope to reduce stray light. VIIRS will have 22 bands, some of which will combine capabilities on MODIS; two nested spatial resolutions; and 8 or 16 detectors per scan. Some bands will have dual gain and all will have constrained pixel growth with increasing scan angle. There have been some recent design changes - the new baffling will minimize stray light much better than MODIS and SeaWiFS, the solar diffuser (SD) and solar diffuser stability monitor (SDSM) will be evolutionary from MODIS, and they are planning to use 2nd order calibration polynomials for all bands. The V-groove blackbody (BB) and the characterization testing will be similar to MODIS. Some issues that Dr. Privette highlighted are the vendor's difficulties with active fire characterization for very large or hot fires; the 645 nm band was

recently widened to 80 nm to accommodate greater dynamic range (avoid saturated pixels for the imagery product); the 751 nm band center wavelength was changed to 746 nm; the NASA geolocation requirements (200 m at 3 sigma) are not an IPO requirement; and consideration is being given to adding a 6.7 micron band for water vapor for FM3 and beyond.

He said that the NRA for an initial science team to evaluate the vendor's science algorithms is expected soon, and a second science team selection to develop/enhance products will be made closer to the launch of NPP.

### **NOAA's Plans for Near Real Time Data**

Bruce Ramsay began by showing a chart of MODIS Data Flow in near real time. He announced that a high volume data line will be installed soon, which should help them to provide products to users. He showed a table of product oversight and service oversight panels, and explained a couple of key elements that NOAA is working on now, such as aerosols, volcanic ash, and land surfaces (wildfires, snow and ice, and MODIS fire products) that are in use now. In addition to wildfires, he said that the ocean color and polar winds people have been doing really well, and they will go into operations this month. He showed an image of the near real time processing system, saying that the goal is to process the transmitted data within 180 minutes of each pass. Ramsay showed a number of images of MODIS fire products, and then explained that there is a GIS system that will bring a variety of products online. He displayed a number of slides showing representative images of the different products that NOAA is producing, such as Caribbean chlorophyll and the SST over Mexico. He finished by explaining that the imminent high-speed data communications link will make even more products possible.

# Atmosphere Products Validation and Status

## Global Distribution of High Clouds - MODIS Compared to HIRS

Dr. Paul Menzel and his group did a study of Extending HIRS High Cloud Trends with MODIS. He showed 12-year trends that show evidence of the effects of orbit drift and ancillary Tsfc. He then showed a graph displaying how HIRS finds clouds by height. Most noticeable in this graph is a decrease of cloud detection in northern mid-latitudes. Next he showed a slide comparing graphs of the Frequency of Clouds Over Ocean to the Frequency of Clouds Over Land, suggesting that most of the decrease in cloud detection occurs over land. Dr. Menzel questioned whether this was right or not, suggesting that the ancillary Tsfc might be causing some of this decreased detection.

Dr. Menzel then explained how high thin cold clouds can be confused with low thick warm clouds. He showed the equation used to determine cloud properties via CO<sub>2</sub> slicing, and explained that different ratios will reveal cloud properties at different levels.

He explained that they generated clear sky radiances in cloudy FOVs in HIRS by interpolating nearby clear FOVs. Clear sky is identified using an IR Window Moisture Corrected Brightness Temperature Test against a-priori surface temperatures. He explained that data from NOAA satellites 10 through 16 were included in the data set, and that generally they were in pretty good agreement, but he pointed out a fair amount of satellite-to-satellite variability that they can't figure out as of yet. There was some indication that orbit drift to later in the afternoon was increasing the detection of cloud; the GOES Sounder supports this with increased detection of cloud from 14 to 18 LST.

MODIS studies start with the MODIS Cloud Mask to determine cloud presence. He listed some differences between MODIS and HIRS, and when Dr. Menzel showed a comparison of HIRS and MODIS global radiances, he noted that though they were not identical, they were close. He showed a number of graphs that displayed the differences between MODIS and HIRS when detecting the frequency and opacity of clouds (for a number of types of clouds) over land and water.

He concluded his presentation by noting that trends are beginning to emerge in HIRS data; there are orbit drift issues; and pathfinder reprocessing is enabling a new look. Extension to MODIS is beginning. HIRS and MODIS total cloud cover are roughly the same over water, and MODIS has more high and middle clouds than HIRS over both land and water surfaces. HIRS found more high thin clouds than MODIS in the tropics over both land and water for day and night, but MODIS has more high thick clouds than HIRS in both the tropics and 20-60N. Lastly, Aqua MODIS will help because its detectors are less noisy.

## **MODIS Polar Water Winds Impact on NWP**

Dr. Jeff Key said that this is a relatively new project for which they have seen positive results recently. Their motivation is that there are very few observations of winds in the Polar Regions.

There is a long history of geostationary wind retrievals, but the problem now is how to track a cloud or water vapor feature when a different portion of the earth is viewed in each successive orbit. Dr. Key demonstrated how visual features can be tracked by a non-stationary orbiter, indicating that it can be applied to winds. The wind retrieval methodology comes from the geostationary world, and includes targeting of clouds in the IR window channel 11 micrometer region and water vapor features in the 6.7 micrometer region; tracking using a cross-correlation technique, using NWP grids as a first guess, and using image triplets for a consistency check; and wind height assignments with the IR window, CO<sub>2</sub> slicing, or H<sub>2</sub>O intercept methods. Unlike geostationary satellites at lower latitudes, it is not possible to obtain complete polar coverage one snapshot at a time with one or two polar orbiters. Instead, winds must be derived for areas of overlap in two or three successive orbits. Much better coverage will be possible with two MODIS sensors in orbit.

Dr. Key showed an example of a detailed case study with MODIS L1B data from Goddard Space Flight Center, which covered a 30-day period over both Polar Regions. He said that after they applied quality control measures, they were able to obtain about 25,000 wind vectors per day at low, mid, and high levels. Most vectors are obtained from the water vapor channel. Dr. Key said that the MODIS winds compare well with radiosonde winds in the Arctic, but there are very few radiosondes available for comparison in the Antarctic.

Model impact studies have been done by ECMWF and the NASA DAO. They compared forecasts with and without MODIS winds, and found a significant positive impact on forecasts in the Arctic, Antarctic, and the Northern Hemisphere extratropics. In essence, assimilating MODIS winds extends the accuracy of the forecast by about four to six hours. It was shown how differences in the 500-hPa height-field in the Arctic can propagate to the upper mid-latitudes without the MODIS winds.

He concluded by saying that the study has demonstrated the feasibility of deriving tropospheric wind information at high latitudes from polar-orbiting satellites. There are some unique challenges yet to address (such as the irregularity of temporal sampling, varying view geometries, the complexity of surface features, and particularly the height assignment of low clouds), but the early results are very encouraging. He noted that MODIS polar winds are being retrieved in real-time (5-8 hour delay), and will be implemented in NESDIS operations in 2003-2004.

## **MODIS Near-IR Water Vapor Algorithm and Cirrus Reflectance Algorithm Status**

The first images Dr. Bo-Cai Gao presented were examples of the visible vs. water vapor detection channels over the eastern half of the US. He explained the color scheme and pointed out that more water vapor is visible in the false-color image than in the true-color image. He indicated that MODIS data agrees quite well with MWR measurements and correlate especially well in clear conditions, though there is more deviation in cloudy conditions. Dr. Gao showed a number of false-color images of water vapor for the months of December 2000, March 2001, July 2001, and October 2001 over Asia in the near-IR and gave a brief explanation of their significance. Next he showed false-color water vapor images of two months over Australia that illustrated the differences between a normal and an El Niño year (January of 2001 and 2002). The last set of water vapor images featured four months, December 2000, March 2001, July 2001, and October 2001 of global near-IR water vapor composites. Dr. Gao ended his discussion of the water vapor algorithm by showing two time-sequenced movies of water vapor retrieval over Africa and the US for the period of November 2000 thru May 2002.

Dr. Gao then discussed the Cirrus Reflectance Algorithm by showing the wavelengths MODIS detected cirrus at, and a comparison of images from the US west coast in true-color and cloud-cover-only modes. The cloud-cover-only image showed how many more clouds there were than appeared in the true-color image. Dr. Gao then made the same comparison in the Arctic region. To illustrate the difference that this algorithm makes, Dr. Gao showed a slide comparing three images: an uncorrected true-color image, a cirrus-only image, and the true-color cirrus-corrected image. He stressed that this product can be used to improve high cloud optical depth over both land and ocean.

In closing, Dr. Gao said that he expects that these data products will have important applications in meteorology, hydrology, and climatology.

## **Comparison of MODIS and Model Global Aerosol - A Movie of One Year Data**

Dr. Yoram Kaufman explained that the products in comparison were from MODIS over ocean (aerosol optical thickness, fraction in fine mode, effective radius, spectral flux at TOA), MODIS over land (aerosol optical thickness, fraction in fine mode), and AERONET (aerosol optical thickness, fraction in fine mode, size distribution, absorption/scattering). He showed two charts comparing MODIS and AERONET (from August 2000 to November 2001) that expressed the validation of aerosol optical thickness over both land and ocean; a series of images that expressed the frequency of aerosol retrievals by season; and a series of images that expressed the average optical thickness by season.

Dr. Kaufman said that the questions the team is asking are whether we can “fingerprint” the anthropogenic factor and, if so, can we estimate the aerosol forcing on climate to change? The huge advantage of MODIS, he said, is that through it we get almost global coverage every day. The comparison of GOCART to MODIS seems to show the fingerprint of anthropogenic influence. Dr. Kaufman noted that AERONET data was used to supplement the MODIS data. Further, the comparison of MODIS’ fine and coarse modes of aerosol to each other seems to reveal more aerosol optical thickness in the fine mode and more climate forcing. He showed a movie that illustrates aerosol transport on a global scale over an entire year.

Dr. Kaufman noted that a comparison of MODIS data to existing models shows that the models are doing a pretty good job, but that there is room for improvement in both the models and in our understanding of MODIS data. The MODIS to GOCART comparison revealed similar results. Overall, he indicated that MODIS gives much higher values of optical thickness than GOCART model.

For the future, they plan to do MODIS and AERONET observations of anthropogenic aerosol global forcing of the climate in cloud-free conditions. Specifically, they will study aerosol forcing using MODIS and CERES, improve aerosol simulations using GOCART, use NCAR in aerosol assimilation, and use GISS in climate models.

### **Revision of the Aerosol Algorithm for Absorption and Nonsphericity & Validation for the 2001 Data Set**

Dr. Lorraine Remer announced a special section on Aqua MODIS in an upcoming GRL issue that will include one paper discussing validation and another discussing cloud mask and spatial variability.

Dr. Remer showed a number of graphs describing MODIS and AERONET optical thickness error bars for Brazil sites and the Eastern US/Ocean. The Eastern US/Ocean had 77% of the data points within error bars, and 82% of the Brazilian data points were within the error bars. Globally, all areas except US East Coast were least 60% within error targets (56% East Coast), some areas as high as 85%. Significantly low areas included the Saharan region (only 37%), and the Mediterranean Ocean (59%). For MODIS alone, 76% of Land and 68% of Ocean retrievals were within expected errors.

The Land algorithm update is going into Collection 4 and is based upon the question of how dark the “dark targets” have to be (suggested by Dr. Eric Vermote). The new version increases the number of retrievals significantly without a comparable increase in errors. The Sediment Mask update will go into Collection 4 as well. Dr. Remer pointed out that the new mask does not mistake smoke or dust in the air for sediments in the water. Other updates that will go into Collection 4 include spatial variability, high AOT cutoff, regaining of retrievals in dust, and dust over glint.

Dr. Remer showed a chart of Operational Aerosol Models using 1995 knowledge to illustrate Biomass burning vs. Urban/Industrial pollution. Because validation using the 1995 model showed errors, they changed the models to increase accuracy by redefining the world's zones.

Future work will include the retrievals of non-spherical dust aerosols (US Atlantic retrievals are 77% within error targets, the Mediterranean is 59%, and the Saharan is 37%). Dr. Remer pointed out how the Aqua data set is helping to extend what Terra has been doing.

In summary, Dr. Remer said that the primary aerosol products are valid within pre-launch error estimates, and they have made the first-ever operational retrieval of aerosol over land. Additionally, they have improved the retrieval of aerosol over oceans using AVHRR data. The fine-mode/coarse-mode division is a significant step forward, and they are making changes to fix small issues such as sediments. Some of these changes are to "re-call" retrievals, such as dust in glint and to make extensions over land. The non-spherical phase functions will be a major innovation, but are not ready for Collection 4.

### **Microphysical Properties of Clouds**

Dr. Bryan Baum explained recent improvements made that will go into Version 4 and upcoming reprocessing efforts; semi-arid land will be less uncertain in clear sky regions and there will be better discrimination between low clouds and clear sky for sun glint. He then focused on the western portion of South America to give examples of Operational Cloud Products, Cloud Temperature, Infrared Cloud Phase, and MultiLayered Clouds, and followed this with a more in-depth explanation of the improvements made in Daytime Multilayered Cloud Detection and Retrieval of Optical Thickness and Particle Size. They can isolate what they think are ice and water clouds, and then classify the rest as overlap that they separate from the rest of the products. By staggering arrays across the scene, they can perform multiple analyses of pixels (up to 16 times each) that greatly increase the confidence of classification. They are trying to fold this method into the analysis. Dr. Baum listed the improvements made for the Collection 4 Code Delivery; there is a new high resolution surface albedo map based on MOD43; a new cloud phase decision algorithm that merges results from the IR (8.5 and 11  $\mu\text{m}$ ) and decision tree (based on cloud mask) approaches; serious algorithm problems were solved (polar retrievals, use of pre-calculated cloud property libraries); and there was a large reduction in the number of unsuccessful retrievals.

Dr. Baum illustrated how Aqua MODIS data is augmenting Cloud Fraction Ice; Cloud Top Temperature Day (Mean); Cloud Optical Thickness Ice (Mean); Cloud Effective Radius Ice (Mean); Cloud Fraction Water; Cloud Optical Thickness Water (Mean); and Cloud Effective Radius Water (Mean).

Dr. Baum noted that the comparison of Aqua MODIS to Terra MODIS shows remarkable consistency. Many improvements have been implemented for retrievals of cloud optical thickness and particle size, including the polar regions, cloud phase, fewer unsuccessful retrievals, and the use of MOD43 to improve characterization of multispectral surface reflectances. For the future, the highest priorities are mixed phase clouds and multilayered clouds.

### **Atmosphere Discipline Summary**

Dr. Paul Menzel concluded the first morning plenary session by summarizing the Atmosphere Discipline's actions. The algorithm stabilization/product validation has been performed for cloud mask, TPW, O<sub>3</sub>, CTH, and aerosol cloud properties. Five papers have been submitted to the IEEE TGRS Aqua Issue, and there are upcoming papers in JGR, Nature, and JAS. A CRYSTAL field experiment was performed for ice cloud investigations, and progress has been made in the detection of cloud shadows. S/W updates have been made to accommodate Aqua data, and the initial product flow looks good. Some Aqua concerns include near real-time geolocation (there is a missing position sensor), specifically for polar winds; an offset between warm-cold focal planes and TPW; and missing 1.6  $\mu\text{m}$  cloud optical properties. Improvement has been made in Atmospheric Total Column Water Vapor both at specific locations and globally. They have also developed an awareness of spectral response differences.

Near term plans for the Atmosphere Discipline include moving forward on global IR radiance bias (observation vs. calculation) adjustment sequencing of 8-day clear sky composites in the forward stream as well as in reprocessing. Level 3 products will be animated for easier quality control, and they will perform intercomparisons of complementary TPWs. ATBDs to be updated by the end of September 2002 include algorithm evolution, Aqua adjustments, and quality indicators. Finally, IR calibration in November 2002 will include a MAS and SHIS under-fly of Aqua.

Dr. Menzel finished by highlighting how having Terra and Aqua MODIS instruments will result in better polar winds; improved diurnal process studies of aerosols, moisture, and clouds; and improved AIRS plus MODIS observations of cloud properties and surroundings.

# **Ocean Products Validation and Status**

## **Ocean Primary Productivity Status**

Dr. Wayne Esaias called the Ocean and Validation Status plenary session together by announcing that the highest-level products would be discussed first, then they would go back through the lower ones.

Dr. Esaias announced that he was there to talk about their Level 4 product, Ocean Net Primary Productivity (ONPP). There will be code changes in Collection 4, including Chlorophyll\_a\_3 and SST day 11-12, and he stressed that Collection 3 didn't have the proper search distance, which didn't allow them to see the bloom in spring. Another change will be a new ONPP Quality Flag definition. They are recommending that people use quality 0 and 1 data points, and possibly quality 2. Collection 4 depth integrations will use shallow water flags, and they've corrected the mapping problems with the VIN 1 grid. They normalized the Global Part Time Series by putting in a new correction factor that enables a better relationship with SeaWiFS. They have also produced PAR and MLD indices.

Dr. Esaias announced that they now have 11 months of Collection 1 reprocessed data. When they do regional analyses, the North Atlantic still has regional coverage, though they have problems with aerosols in Africa. They've done comparisons for Chlorophyll\_a\_2 and MODIS. For ocean coverage, they are getting about 90 percent in a weekly file, which consists of P1 and P2 data. All of these statistics are available on the Oceans Discipline website: <http://modis-ocean.gsfc.nasa.gov/>. In the South Pacific region, the difference between tropospheric region chlor\_a\_2 and a\_3 is very small. From the 39 km maps, the Indian Ocean and the northern equatorial region are behaving as expected.

Dr. Esaias said that they've had to deal with the effects of scaling – the answers they are getting are dependent upon the time and space scales in which the data were gathered, and are also affected by the specific resolutions they work with. In terms of ocean coverage, when they work with daily scale composite coverage, they have to be cautious when they use numbers. Mean global SSTs increased, which increased the positive area. However, the opposite was true of chlorophyll, because high latitudes tended to produce high means and force you to account for missing data.

Dr. Esaias said that the first generation ONPP algorithms are being improved (PPAR-3). Input dependencies have been characterized, and scaling composting effects have been identified. Variations on ONPP due to input products are large; 20% variations can be found globally and 30-80% regionally. Also, an oceans time series comparison is planned.

Dr. Esaias noted that Kevin Woodward, as part of his analysis program, did an exhaustive analysis of the mean change in the P1 and P2 products, and found that the ONPP product is sensitive to

changes in chl and population structure. Dr. Esaias said that even a 20% change in these populations can lead to the equivalent of an anthropogenic increase and could be a very pronounced sink or source. Understanding this is key to understanding the biological pump. Carbon sequestration requires that organisms sink from the surface and be removed from contact with the atmosphere, and that the carbon has little chance of returning to the atmosphere. With this process there is a great deal of difference between coastal and central oceans – on the coast you get strong upwellings which lead to higher populations of algae and more inorganic material being drawn down, and thus more carbon sequestration per square kilometer than in the open ocean. There is an order of magnitude of difference from the upwellings of the coast to the central ocean. Dr. Esaias concluded that they are very pleased with the data. He announced that they should have a year of Collection 4 data by the end of the week.

### **Estimating Chlorophyll Concentrations Using MODIS Fluorescence: A Preliminary Evaluation in Coastal Waters**

Dr. Mark Abbott discussed the role of chlorophyll fluorescence measurements from space. They are being used to improve estimates of primary productivity in the ocean. He explained that SeaWiFS data can be used to measure chlorophyll and PAR (photosynthetically available radiation). MODIS can estimate the absorbed radiation by phytoplankton as well as chlorophyll fluorescence, in addition to chlorophyll and PAR. The MODIS data can then be combined to estimate the quantum yield of fluorescence (how many quanta of fluorescence are produced for a every quantum of light that is absorbed). The quantum yield of fluorescence can then be used to infer the quantum yield of photosynthesis, assuming that the quantum yield of heat remains constant.

The patterns of the MODIS\_Chl, MODIS\_FLH, MODIS\_CFE, and MODIS\_ARP products are helping to refine the understanding of photosynthesis. The general geographic patterns in CFE are what one would expect to see, and many areas show low, relatively constant CFE and chlorophyll that are likely associated with highly productive recycling systems. Regions off northwest Africa and the Arabian Sea are characterized by apparently high chlorophyll and low fluorescence. Possibly absorption-based algorithms are confounding aerosols or dust with chlorophyll.

The basic FLH measurement has been validated with aircraft measurements made by Frank Hoge (see next section). Comparison of the aircraft and MODIS estimates of FLH from waters off the U.S. East Coast are consistent across a broad range of water types. Comparisons of MODIS chlorophyll are matching up well with the measurements from ships, except at high chlorophyll values where the MODIS estimates are consistently too high. However, the relationship of MODIS and ship-based FLH remains linear, even at high values. This suggests that absorption-based chlorophyll algorithms may be confounding sediment and other non-chlorophyll

materials with phytoplankton chlorophyll in productive nearshore waters. However, FLH can distinguish between these water properties. Thus the use of MODIS FLH to estimate chlorophyll in coastal waters may be a significant advance over traditional absorption-based algorithms. However, one must distinguish physiological from bio-optical factors.

Changes in fluorescence quantum efficiency will affect any chlorophyll estimates based on FLH. Moreover changes in the quantum efficiency of heat that may arise from changes in the amount of photoprotective pigments can also complicate FLH-based chlorophyll estimates. Studies with phytoplankton cultures in the laboratory are evaluating these physiological effects. They have found that if phytoplankton are in the process of adapting to a change in the environment, CFE will be high. Once the phytoplankton have acclimated, CFE becomes lower and more constant.

In summary, Dr. Abbott said that they are seeing a generally linear relationship between absorption-based estimates and fluorescence-based estimates of chlorophyll, but exceptions are apparent, such as near coasts. They have found that the slope of the line relating FLH to CHL is related to CFE. As for estimating chlorophyll from FLH, the current challenge is that there are many variables that affect  $f_F$ , including photo-protective pigments and absorption cross-sections. It appears, though, that CFE seems to fall into two clusters, so the problem may be tractable. And finally, high values of CFE appear to be associated with communities far from equilibrium.

### **Continuing Validation of Terra-MODIS Phytoplankton Chlorophyll Fluorescence Line Height (FLH) Product: New Airborne Laser Results**

Dr Hoge listed the types of validation techniques – laboratory, ship, airborne, active (laser), passive (SOLAR), airborne + SeaWiFS, and airborne + SeaWiFS + MODIS. With the active sensor (laser fluorsensor) they direct a laser beam vertically downward into the ocean to stimulate the fluorescence of phytoplankton and chromophoric dissolved organic matter (CDOM) together with the water Raman emission. Concurrent passive validation was achieved by ocean viewing and sky viewing spectroradiometers.

Dr. Hoge illustrated airborne validation by use of an image of the version 3 MODIS chlorophyll fluorescence line height (FLH) including concurrent airborne underflight track lines. The validation underflight was conducted from GSFC/Wallops. These validation flights generally cover five types of water masses from coastal, shelf, slope, Gulf Stream, and Sargasso Sea. Excellent agreement was obtained between the MODIS FLH and the airborne laser induced fluorescence of chlorophyll. A correlation coefficient of 0.851 was found. Dr. Hoge said that he considers the MODIS FLH product validated since scientific investigations can be accomplished with the data.

A second laser emission was used to obtain the chromophoric dissolved organic matter fluorescence that has been demonstrated on prior field experiments to serve as a surrogate for the absorption coefficient. CDOM is a dominant absorber on continental shelves and it was shown during this underflight that the MODIS FLH is essentially not affected by the dissolved organic matter. In contrast, the underflight data further showed that chromophoric dissolved organic matter in the coastal regions largely invalidates band ratio algorithms for chlorophyll biomass retrieval.

To date, the airborne validation of MODIS has been confined to the Northern Hemisphere. Field missions into the Southern Hemisphere are in the preliminary planning stages. Several areas of interest include the Argentine Patagonian Shelf because of high productivity and concurrent CDOM variability. Similarly, the Amazon plume is of interest. Very low productivity regions near Easter Island are also of interest to insure a wide range of validation in various water masses.

### **An Algorithm for Coastal Water and its Implementation into the MODIS Processing Stream**

Dr. Howard Gordon said that they are testing the implementation of the algorithm on coastal waters. Case 1 ocean waters are dominated by phytoplankton and their debris, and Case 2 waters are coastal and all other waters not in Case 1. With Case 2 waters there are no bands tailor-made for assessing the aerosols present, and they contain quantities of organic matter that influence the rho in a manner similar to strongly absorbing aerosols. They ended up with 72 separate aerosol models, and expanded the aerosol part as a function of optical fields to get a continuum of models.

Dr. Gordon showed a number of SeaWiFS images and explained how they applied the algorithm to a highlighted east-west track, then compared it to Dr. Hoge's measurement along the highlighted north-south track. The result is a graph where red is the optimization algorithm and blue is the AOL. The blue is below the optimization algorithm, and Dr. Gordon noted that as they get closer to the coast the optimization algorithm will be larger. He noted that they need to figure out the value of S (in the equation) for exact AOL/SOA agreement along the north-south track and compare this to the 8-day mean from SeaWiFS. When DCM is high, they cannot really get chlorophyll because of interference from sediments. Parameter mu is the slope of the size distribution. The winds bring in stuff from the mainland and the values of may become extremely high in the sound because they are not Case 2 waters.

Ultimately, Dr. Gordon said that this algorithm will work in Case 2 waters. When they compare MODIS to SeaWiFS, they match up well in terms of backscattering. When they look at SeaWiFS for a CDM, MODIS gives much higher values than SeaWiFS, but in the broader view, SeaWiFS' values are much higher than MODIS'. When they look at chlorophyll, things get bad for MODIS in the

coastal regions. SeaWiFS gets chlorophyll using the latest SeaWiFS calibration, so the solution for MODIS is just to raise the calibration.

In summary, Dr. Gordon said that the spectral optimization algorithm works well with SeaWiFS. The potential for SOA in Case 2 waters is excellent. The code from MODIS imagery is now in operation, and retrieval problems are believed to be due to MODIS calibration. They plan on working to improve calibration in the 869  $\mu\text{m}$  band, and they will incorporate the 50 m and 250 m bands in a relatively straightforward algorithm. Lastly, they are preparing to make a detailed comparison of the two.

### **Comparison of MODIS and SeaWiFS Chlorophyll Products: Collection 4 Results**

Dr. Janet Campbell said that chlorophyll is the most commonly used ocean color product, and that SeaWiFS recently went through its fourth reprocessing. MODIS has just started its first reprocessing of chlorophyll data, and MODIS Collection 4 data began processing in June 2002. They are close to having one year of uniform code product. On July 9, the SeaWiFS reprocessing was completed. Dr. Campbell then posed the questions – why do we have so many MODIS chlorophyll measurements? What's the difference between them? In answer, she said that originally there were two algorithms: a Case 1 algorithm (Dennis Clark's Chlor\_MODIS) and a Case 2 algorithm (Ken Carder's Chlor\_a\_3). The Case 1 chlorophyll is an empirical algorithm based on statistical regression between chlorophyll and radiance ratios. For Case 1 and 2 waters, we have MODIS Chlor\_a\_3, which is based on a semi-analytic algorithm that accounts for the pigment packaging effect of nutrient status (replete vs. deplete). Chlor\_MODIS and Chlor\_a\_3 are similar, though the Chlor\_a\_3 levels tend to be much higher in the Southern Ocean. Chlor\_a\_3 uses sea surface temperatures. More recently, a third algorithm known as the "SeaWiFS analog" algorithm was added that is based on the same data used to parameterize the SeaWiFS chlorophyll algorithm (OC4.v4). When compared at different averaging periods, the resulting statistics were similar whether they were focusing on daily or weekly composites.

In conclusion, Dr. Campbell said that the Collection 4 SeaWiFS Chlor\_a\_2 is valid by definition since it agrees with the SeaWiFS chlorophyll. As for earlier comparisons among the MODIS chlorophylls, she said that they had had some problems because the quality levels were set differently. In Collection 4, they have made an effort to make quality definitions more consistent. For example, the northern boundary for the highest quality (level 0) chlor\_a2 in December 2000 is farther north in Collection 3 than in Collection 4. She speculated that the quality level was tied to solar zenith, and said that Collection 3 has a lower cutoff.

### **MODIS Bio-optical Data Product Status**

Dr. Dennis Clark said that MOBY now has a five-year time series, and that overall, it took fifteen years to get a five-year time product.

As for the MODIS data products, there have been a lot of changes made in products 19, 23, and 26 since December. Product 19 changes include Parameter 13 – CZCS\_pigment (Chl a + Phaeo has been fluorometrically determined), Parameter 14 – chlor\_MODIS (Chl a mono and divinyl, Chl a allomer, Chl a epimer, and chlorophyllide a have been HPLC determined), and Parameter 15 – pigment\_cs\_total (Chl a + 27 accessory pigments have been HPCL determined). Product 23's Parameter 19 – Total Suspended Matter is now considered a dry weight. Product 26's Parameter 23 – K<sub>490</sub> now uses a SeaWiFS Downwelled Irradiance Diffuse Attenuation Coefficient.

There are a couple of nLw calibrations stabilized-product impacts. Chlor\_MODIS is bigger than the total pigment concentration in regions with high pigment concentration and at high latitudes because the nLw 433 retrievals are too low, and because 490 was stabilizing the 3-band total pigment retrievals. Also, the MODIS nLws scaled to MOBY's stray light corrected nLws were returning higher than expected pigment concentration values in the low concentration regions because the in-water radiometric measurements were not stray-light corrected.

Dr. Clark said that parameters 14 & 19 have been reformulated from 2-band to 3-band ratios (chlor\_MODIS & Total Suspended matter). All products will be forced through Gordon's radiance ratios for pure water. In situ blue water nLws were corrected for stray light with the NIST nominal characterizations. All parameter algorithms were split into two third-order polynomials to optimize the high radiance ratio range.

Dr. Clark showed a number of slides that illustrated the changes and comparisons they have made. The CZCS slide illustrated how just a .25 point shift from December to July resulted in a 20-30% difference in their product. In the SeaWiFS ocean 4 model, they saw commonality around 555, but because they didn't include aerosols, they expect to see large differences, and Dr. Clark noted that no one should expect to see retrieval for chlorophyll concentration. When they looked at the effect of the error in the Band 9/12 ratio for chlorophyll, they found serious problems. They tried switching to a three-band algorithm, but it just got worse because the three-band algorithm's requirements are more restrictive.

The early part of MODIS is not entirely characterized, but for the most part the MODIS and ship data are good. Ratios 440/553 and the three bands don't have many large discrepancies, except for a few outlying points. The percent differences for MODIS and ship data were for the most part good; for pigment concentration they got 10-15% differences, and the percent differences for chlorophyll MODIS and CZCS is 20%. The MOCE and MODIS chi ship track data for December 2 were in good agreement; though they were remarkably different from the March 2, 2001 cruise.

In closing, Dr. Clark reported that recent Miami characterizations/calibration results have solved most of the major

nLw retrieval problems. The present products are computationally validated and initial validation results indicate that the pigment retrievals are within 30%. MOBY observations are now operational for Aqua, though the K measurements on MOBY are off. In July they acquired two calibration/validation data sets with MODIS Terra, Aqua, and SeaWiFS overpasses. Finally, there are MODIS Validation/Initialization cruises scheduled for September and October 2002 in the Chesapeake Bay and Hawaii, respectively.

### **Current Status of the Terra MODIS Sea Surface Temperature Measurements**

Dr. Robert Evans first explained the focus areas of the L1B calibration and validation versions:

- I. Terra Reprocessing – version 3 L1B
  - a. Collection 4 coefficients, validated
- II. Terra Forward processing – version 4.0.5 L1B
  - a. Collection 4 coefficients, validation comparison in progress
- III. Aqua Forward processing – pre-launch LUT – V3
  - a. Collection 3 preliminary coefficients
- IV. Aqua Forward processing – first on-orbit LUT – V4
  - a. Repeat calculations based on LUT

Dr. Evans explained that everything is based on radiative transfer based pre-launch SST retrieval equation derivation, which brings into question the IR channel on MODIS. They use a regression-based operation retrieval equation derivation pathfinder, and validation is based on comparison to contemporaneous co-located radiometric SST. Finally, auxiliary validation is provided by buoy observations to extend space, time, and in situ comparisons.

Dr. Evans pointed out a particularly good comparison of Aqua and Terra MODIS SST and SST4. The pixel noise ratio is about 0.03C along scan. They compute the Terra coefficients with the AVHRR Pathfinder, and also do it for Aqua and Terra MODIS SSTs. The MODIS SST comparisons to AVHRR Pathfinder turned out really well, as did the Aqua and Terra SST comparison of L1B.

Dr. Evans said that they validated MODIS SST on the ocean using ship data; they took cruises with M-AERI to validate the instrument. The readings were taken under clear sky conditions and routinely processed from January to May. He stressed the SRDSS are meeting or exceeding any goal they've set. Explorer of the Seas M-AERI and MODIS match up extremely well for SSTs; however, there is some bias in radiative transfer.

There are a few things that they are concerned about and want to improve. Near surface temperature gradients are a reality, and

MODIS measures temperatures at the top of the ocean. Shipboard measurements are taken at a lower depth near the ship's intake underwater, where it's colder. There is a time evolution of near-surface thermal gradient; depending on the local time and depth, the temperatures between the ship measurements and the MODIS measurements will vary. To avoid these irregularities, they will probably only use nighttime temperature measurements. This points to the need for validation. The infrared bands of MODIS form self-calibrating radiometers. The retrieved SST fields are validated to confirm the procedures used to generate them and to validate that the radiometer data are performing as believed. Therefore it is the atmospheric correction algorithm that is being validated. This requires instrumental imperfections to be known and the data corrected. Another factor is the wind speed dependence of the skin effect temperatures measured a couple of meters below the surface. If there are wind speeds greater than 3 m/s, we have a correlation between the surface temperature and wind speed on the satellite data. They took nighttime observations of MODIS and Aqua as well as daytime. There was a big difference between skin and bulk temperatures taken aboard the ship – it was as much as a couple of degrees. When they merge the products of both Terra and Aqua MODIS, they get nearly total coverage.

In conclusion, Dr. Evans said that Collection 4 v3 reprocessing has been validated; the M-AERI radiometric comparison is better than 0.25 Celsius; buoy comparison supports M-AERI validation and extends it to a wider range of space, time, and in situ conditions; Collection 4 v4.0.5 forward processing validation is in process; Aqua pre-launch equation coefficient test has been completed, night Terra-Aqua merged image provides near complete global coverage (not counting persistent cloud presence); and Collection 3 Aqua is waiting for the delivery of an on-orbit LUT. Outstanding Aqua issues include verifying the brightness temperatures and the non-linear behavior of bands 31 and 32. Preliminary SST validation shows that Terra MODIS is compatible to Aqua MODIS.

### **Current Status of the Terra MODIS Visible Water Leaving Radiance Measurements**

Dr. Evans' second presentation began with an explanation of their calibration approach. They use corrected at-surface nLw, atmospheric, and surface reflectance. MOBY (at Hawaii) is the reference for in situ validation; more extensive validation for other regions will require completed reprocessing using SIMBIOS reference data. The cross-scan is referenced to detector 5 because of its low noise at location at the center of the detector array. The mirror side balance is referenced to side 1. To remove time trends they compared modal peak for areas surrounding MOBY to MOBY, high temporal density, and they were not dependant on cloud-free conditions. For calibration they adjusted MOBY-MODIS single pixel match-ups to remove biases.

Dr. Evans showed a number of comparisons of Terra images with and without correction, and also MOBY to MODIS comparisons of the 412 nm detectors. Overall, Terra's bias is very close to zero. MOBY, on the other hand, cannot make 667 and 678 waveband measurements. With Terra and Aqua L4B, we can see the difference in radiance level. The general suggestion is to put these together to see very close to SS. They must also deal with sun glint, but they're getting close to total coverage.

In conclusion, the Terra unrecorded mirror-side cross-scan detector and time variations each exceeded 30% in nLw. Collection 4 v3L1B (reprocessing) nLw is validated. Some caveats include variations of  $\pm 5\%$  in nLw are expected for cross-scan, detector-to-detector, mirror side, and time. There was a Collection 4 v4.0.5 (forward processing) correction, and the validation tests are in progress and are nearing completion. The Aqua detector, mirror, and cross-scan preliminary corrections are in testing and need to be verified for polarization correction factors. Collection 3 Aqua is waiting for delivery of on-orbit LUT, and a manuscript with complete details is nearing completion.

### **Performance of MODIS Semi-Analytic Ocean Color Algorithms: Chlorophyll\_a Absorption Coefficients, and Absorbed Radiation by Phytoplankton**

Dr. Kendall Carder said that in high waters, there is so little light that there are not any photosynthetic pigments. He detailed the absorption spectra for water, CDOM, and phytoplankton, and noted that chlorophyll absorption can vary. Dr. Carder said that they have developed a blending scheme to transition between fully packaged and unpackaged pigment parameterization for waters with SST between NDT-1 and NDT-4 degrees C (what does NDT mean?). Chlorophylls were falling from the supplement to the subtropical. When they looked at chlorophyll\_a3 applied to the arctic region, they got no bias on quartile plots, and in general they got no bias in the chlorophyll\_a3 algorithm performance versus OC. When they compared chlorophyll\_a2 and \_a3, they found higher volumes at higher latitudes and not much difference in the summer at the low chlorophyll end. They found high pigment package effects at high chlorophyll.

When they looked at SEABASS chlorophyll\_a, they found preliminary match-ups (30-40 points), and Dr. Carder expressed the possibility that some of those places will have regional averages. SIMBIOS has done a match-up for non-shallow depths of the chlor\_a2 and \_a3 data sets between MODIS and shipboard measurements, but noted that they do not yet have enough summer data.

Dr. Carder noted that they did preliminary destriping by using a destriping filter over a fairly large area, and found that quite a few stripes remained. If they used that filter over smaller regions, the small amount of striping seen in chlorophyll\_a would go away, but larger scales are problematic.

In conclusion, Dr. Carder said that the chlorophyll\_a3 algorithm performance has improved for high latitude upwells in scenes with little or no bias. The SeaWiFS OC4 algorithm performance in the southern ocean for field radiance is biased on the low side by greater than 40%. The chlorophyll\_a2 global mean for November 2000 was .215 mg/m squared, while the chlorophyll\_a3 value was .32 mg/m squared. The Global ocean primary production calculated with the MODIS chlorophyll\_a3 algorithm is expected to show an increase of SeaWiFS based values of about 29%. Finally, preliminary non-shallow match-up field data for Terra chlorophyll\_a3 and \_a2 results show errors of 49% and 59%, respectively.

### **Coccolith-Calcite Concentration Validation and Status**

Dr. Balch began by asking and answering the question “What are coccoliths and coccolithophores?” They are plants that produce calcium carbonate scales (which themselves are highly light scattering). Each coccolith is in the range of 2 microns in diameter. He pointed out that these organisms have been inadvertently featured on the Earth Observatory’s Natural Hazards site (<http://earthobservatory.nasa.gov/NaturalHazards/>), in images of smoke over Norway, originating from North American fires.

Dr. Balch explained that in some coccolithophore blooms, the PIC can be a 1° determinant of nLw or normalized water leaving radiance. They have measurements for about five years from the Gulf of Maine for coccolithophore calcite, backscattering, ship-derived nLw, and satellite-derived nLw. Among all PIC in the water, coccoliths play the major role in light scattering, especially at 412 to 550 nm due to a) their high scattering per unit mass and b) their high concentration (often >10,000 per milliliter). The main interest in these measurements has to do with carbon sequestering. Just based on errors in water-leaving radiance from MODIS (of ~5%), then the predicted error in the PIC algorithm is expected to be a few µg PIC per liter. However, due to the different species’ reflective properties (and other potential scattering materials in the water), a more realistic error is between 1 and 30µg PIC L-1.

Dr. Balch then turned to the topic of “Measurements of CaCO<sub>3</sub> and bb from ships”. The original data for the 2-band algorithm look-up table are data for PIC versus optically derived from the 1991 coccolithophore bloom south of Iceland. These data suggested an overall error of ~30µg PIC L-1 due to differences in the ratio of detached coccoliths and plated cells. The algorithm works better at higher concentrations. He then added to this data set with measurements from the Arabian Sea, the Florida Straights, flow-cytometer-sorted field samples, and the Gulf of Maine. However, they still needed to study some higher PIC concentrations, so they made a simulated coccolithophore bloom using coccolith chalk (calcite sediments cover ~1/4 of global marine sediments). The important part of the experimental design was the ability to choose the day on which to deploy it to maximize the possibility of satellite coverage. The chalk experiment measurements collected by the

ship were highly consistent with the MODIS measurements. They found that satellite measurements compared to ship data at level zero fit within the variability seen from the ship, and are similar to SeaWiFS data.

In summary, Dr. Balch said that the algorithm is working well. The absolute RMS accuracy of the PIC product is  $\pm 30 \mu\text{g C/L}$  for mixtures of unknown PIC particles. For mono-specific features, the relative sensitivity of the PIC algorithm is much better than the  $30 \mu\text{g PIC/L}$ , more like  $3\text{--}5 \mu\text{g/L}$ . He showed data from a 2002 Gulf of Maine coccolithophore bloom as proof of this. In the summer of 2003 they plan on doing another chalk experiment. They will contribute other particulate material to bb, and will do validation work to refine residual errors and improve accuracies of PIC retrievals.

## **Ocean Discipline Summary**

Dr. Esaias summarized the Ocean Discipline portion of the plenary sessions. He stated that reprocessing is going well; ten months are complete at 1.8 terabytes, and the validation of many products is progressing well. Their experience with Terra is really paying off with Aqua; the L1 data products are very well behaved and the oceans global products are produced within 24 hours, though he cautioned people that validation still takes time.

The Terra SST is the best current IR SST product, and Aqua promises to be better. The calibration of the Terra MODIS ocean visible product has been an extreme challenge, but the results are spectacular. There is a suite of MODIS ocean color products available for research and evaluation that will provide the basis for improved science. The fluorescence data are more sensitive than they expected, having been shown to be useful in case 2 waters. Research is progressing on global implications for physiological ecology, and there are impressive validation efforts ongoing with independent AOL observations. MOBY and MOCE nLws are the world standard of reference for initialization of ocean color satellite data sets. They have improved coordination with SIMBIOS, including doing match-ups with in situ data from SeaBASS, merging Terra chlor\_a\_2 and SeaWiFS chlorophylls, and are preparing for VIIRS/NPP. The NOAA near real-time effort is bearing fruit. Finally, the use of high-resolution coastal bands is improving.

Dr. Esaias stressed that their current areas of emphasis are multiple. Terra validation and Aqua initialization are very important, as is the production of Terra and Aqua products. They need to continue focusing on distribution and outreach, and there are recomposition changes coming up. They need to focus on validation everywhere, but especially in the southern ocean. The reprocessing effort is exemplary. Dr. Esaias said that their current issues are with the VIIRS instrument. It is promising for a follow-on instrument, but the pathway to VIIRS science products is not clear. The pathway needs to be clearly defined, they need to set realistic scientifically useful goals, and propose realistic findings.

# Land Products Validation and Status

**July 24, 2002**

## **MODIS Fire Validation and Status Report and Rapid Response Update**

Dr. Chris Justice opened the Land Products and Validation Status section of the plenary sessions by presenting the recent activities associated with the MODIS Fire Product. He announced that the active fire algorithm continues to be refined by Louis Giglio based on extensive QA and preliminary validation results, and that the algorithm has changed from version 3 to version 4 (the latter version is used in the MODLAND Rapid Response System). The Fire Rapid Response System, managed by Dr. Jacques Descloitres, continues to increase the visibility and use of MODIS fire data and is providing an extremely useful tool for Aqua product evaluation. The objective of the active fire validation strategy is to determine product accuracy. The validation of MODIS active fire products using ASTER data has been developed by Dr.s Czsisar, Giglio, and Morissette, and results were shown for savanna vegetation in Africa. The active fire product can be considered validated at Stage 1. The approach is now being applied at a globally representative sample of scenes. MODIS will feature improved fire detection probability in Collection 4, increasing its sensitivity to detect small fires and decreasing the number false detections. Dr. Justice detailed a comparison with a direct thresholding fire detection method developed by Dr. Vermote and showed that the current configuration gives comparable rates of detection, but different false-alarm characteristics. He announced that the climate modeling grid layer for fire is ready to go into production.

Preliminary intercomparisons of Terra, Aqua and AVHRR fire data show the Aqua fire product to be performing well. The MODIS Burned Area product has been reprocessed for the initial test region of Southern Africa. The product developed by Dr. Roy gives monthly burned area distributions at 500m and accounts for bidirectional effects in the data. Emphasis has been placed on validation of the MODIS Burned Area product. A comparison was made with a Burned Area Product being developed by the JRC Ispra using SPOT Vegetation data and emphasizes the need for independent validation data sets and the opportunity for international coordination through the CEOS Land Product Validation Working Group. An example of how to use the burned area product to estimate regional emissions of CO<sub>2</sub> was developed by Stefania Korontzi.

The fire group is currently working on product validation, active fire algorithm improvements, burned area product improvement, fire energy development and community outreach. The latter is being undertaken through the GOFD/GOLD-Fire program and is involving fire scientists for example from Russia, Africa, Australia, Mexico and Brazil in MODIS fire product evaluation and validation activities. The Fire Rapid Response system provides an important tool for

community outreach and data applications. Code has been provided for Direct Broadcast Stations to develop similar products.

### **IDS Degraded Data Set**

Dr. Eric Vermote began with the announcement that the MODIS Multidisciplinary Data Set contains versions of all the Atmospheres products, quite a lot of the Oceans products, and most of the Land products. He demonstrated on his Linux-based laptop how to use the CD, and made note that all of the data on the CD is in HDF format. The CD is easy to use because all that the user has to do is click on the data to see/use it. He mentioned that there are simple scripts that can be used to create animations from the data set, and that GDAAC included on the CD an official HDF tool that allows users to zoom in on the image, see the data, reproject it on the fly, and save the data to a binary file. There is another script that allows users to create a time series of the data set. Overall, he said that it is possible to do a lot of data manipulation, and there is more than a year of MODIS data on the CD.

The idea, Dr. Vermote said, is to use this data as a bridge to the higher resolution products. The point is that they now have a global data set that people have been long wanting, and it comes with a tool to help people use the data. The ftp address where the data on the CD can be downloaded is:  
[ftp://modis.gsfc.nasa.gov/pub/Data\\_Sets/](ftp://modis.gsfc.nasa.gov/pub/Data_Sets/).

### **Surface Reflectance Product Status and Validation**

Dr. Vermote announced that the MODIS Aerosol Optical Depth validation marks the first time ever that we have operational aerosol detection over land. Dr. Vermote said that internal masks have been developed to filter out snow, cloud, and fire contaminations, and that the aerosol 1km retrieval validation is on-going.

Dr. Vermote said that the team has been working on that product and using it to do a comparison of MODIS spectral emissivity and ground level temperatures to ASTER data as a method of validation. The team has also worked on developing a better cloud mask and comparing it to the official cloud mask product (MOD 35). Another product is an internal cloud shadow mask that will extend analysis to 92 possible cases.

In conclusion, Dr. Vermote said that the MODIS narrow land bands located outside of strong gaseous absorption ranges features an operational aerosol retrieval method that makes it possible to produce surface reflectance at a global scale on a daily basis. This makes it possible to invert the directional surface properties and compute climate model parameters (albedo). Validation of the reflectance product is ongoing to produce a realistic estimate of error bars under representative atmospheric and geometric conditions. Aqua MODIS is significantly extending the usefulness of land data. Aqua MODIS has much less striping on Band 7 than its Terra counterpart, which should help to increase the quality of data

gathered, and Aqua MODIS' SWIR Bands (except for Band 6) look radiometrically better than those of Terra MODIS.

### **Snow Cover and Sea Ice Status**

Dr. Dorothy Hall said that the team hopes to have a snow albedo product out in the fall, and further in the future a fractional snow cover 500-m map product. Dr. Hall pointed out that on the CMG daily snow maps at .05° resolution, the maps show fractional snow cover from 40-100% in each pixel, and will be 0-100% coverage in Collection 4. They have been enhancing existing products, including instituting a thermal mask to eliminate spurious snow cover, which will come out in Collection 4. The cloud masks from the University of Wisconsin map too many clouds, so they are working on a more liberal cloud mask that will increase snow mapping by 75% and decrease cloud detection by 18%. They hope to get this mask into Collection 4 as well.

Dr. Hall said that they have been working on validation since the beginning of the Terra data stream, and have been looking at LANDSAT data and operational snow products from NOAA as well. This year they are focusing on the NOAA IMS product and have found that sometimes MODIS detects snow where IMS does not, and vice versa. The areas where MODIS is confusing snow with clouds are areas that they need to work on. The 8-day products are not good for doing validation, so they are working with dailies instead. MODIS and IMS agree on snow cover 80% of the time. They are comparing MODIS to SSMI maps and have found that MODIS visible data make better maps earlier in the snow season, but SSMI does a better job later on. They have also been working on data assimilation modeling, and are using CMGs to correct modeled snow output. They hope to have results by the next Science Team Meeting, and they will have CMG products out soon. They found a station in Alaska that gives comparable air temperature data that they can compare to MOD29, and though they only have four cases right now, they have found a difference in air/ice temperatures from .2K to 1.5K.

In closing, Dr. Hall said that they consider the snow and sea ice products to be validated, and the ice surface temperature product to be provisional, but it will be validated after a March experiment.

### **New Land Cover and Land Cover Change Products Using MODIS Data**

Dr. John Townshend's presentation covered three products within the MOD44 product suite – the Vegetative Cover Conversion Product, the Vegetation Continuous Field Product, and the Intermediate Composite Product.

The Vegetative Cover Conversion Product focuses on tree and land cover using derived metrics for characterization and features an algorithm for automatic generation of global tree cover estimates that uses a regression tree method. Dr. Townshend reported that as of

July 2002 they had reached 100% global processing of 250m data. In Collection 4, all 250m data will be produced and archived globally. A simplified, near real time algorithm is planned for Rapid Response in 2002. They plan on doing fieldwork with the USFS this summer, and plan to update the LUTs with each reprocessing. The Aqua overpass time will improve cloud-free data in the tropical forest, thus increasing their ability to detect changes. Dr. Townshend noted that they need to continue developing the month-to-month product, and the VCC accuracy depends upon the phenological state of the sample periods.

The Vegetation Continuous Fields Product is an annual 500 m product that provides sub-pixel estimates of forest cover, leaf type, and phenology. Two months ago the team came out with a MODIS 500 m Global Percent Forest Cover Product using year 2000 data, whereas previously they were using 1999 data. They still have to work on the projection ("cricked-neck") issue, but he feels that it is a reliable product. They've compared it with USFS estimates by state and are working to harmonize stats between products. They continue their validation efforts using IKONOS, ETM+, and field data, and also make use of ancillary map sources. They are finished with their initial site in Western Province, Zambia, and plan work at 12 sites in the US and additional sites in Africa. MODIS data offer increased spatial detail and are appropriate for monitoring change, though they must minimize the deleterious effects of compositing. The 1km thermal band is needed to capture certain tree covers, but preliminary tree cover results show general agreement with USFS data. IKONOS offers improved ways to drive the algorithm with proportional estimates tied directly to the variable of interest. They plan to release version 1.0 tree cover by August 15, 2002 via GLCF and MODAPS, and plan on releasing other layers this summer.

The Intermediate Composite Product is complete, and Dr. Townshend said that geolocation looks very good. They have to work around the 250m cloud mask, and there are L2G issues related to maximizing spatial resolution. He noted that all compositing methods have implications for data quality, and they have to go to at least a 32-day composite to get rid of clouds.

Dr. Townshend noted that it is a question of what resolution they should be using. The problem with accuracy at different resolutions is because of contamination from outside sources. Finally, Dr. Townshend said that the global 500m Mosaics will be available via the GLCF: <http://glcg.umiacs.umd.edu>.

### **Validation of MODIS Cloud Products Through an Inter-Comparison with MISR, GOES, and Ground-Based Radar/Lidar**

Dr. Catherine Naud and her group seek to understand what biases and artifacts exist in the MODIS CO2 slicing Cloud top pressure (CTP) and MISR stereo Cloud top height (CTH) through inter-comparison. They also seek to understand the differences between MODIS and MISR using ground-based mm-radar + Lidar and GOES

CTHs. The group compared MOD06 with MISR-2TC CTHs over the British Isles, then compared cloud top heights to radar at Chilbolton and ARM SGP sites. Finally, they compared the MODIS/MISR CTHs to GOES at ARM SGP sites.

They looked at 27 cases of MODIS vs. MISR CTHs over the British Isles, using pixel-by-pixel comparisons for statistics and calculation of CTH differences. MISR tends to be lower than MODIS on average per scene. MISR seems to be more sensitive at lower levels of the atmosphere than MODIS, but does not detect the highest clouds in multi-layer conditions. Dr. Naud said that her group speculates that it could be a problem of contrast of the high clouds over low clouds, so the algorithm indicates the height of the brighter, i.e. lower, clouds. When the group compared MODIS and MISR CTHs to radar at the Chilbolton and ARM SGP sites, they found that MODIS CTHs agree fairly well with radar measurements (86.67% detection efficiency) and MISR CTHs do up to a point (57.14%). This study did not include an error budget for CTH detection by radar/Lidar.

When they compared MODIS to MISR, they found that when MISR detects high clouds, its CTH is higher than MODIS', and they wondered whether MODIS is less sensitive to high clouds. They found that MISR tends to miss high clouds in multi-layer cloud conditions and found that this is a contrast problem with the AF-AN MISR cameras. They propose adding a modified processing chain to include off-nadir cameras using the new UCL stereo matcher M4 to match successive views. MODIS and MISR compared to GOES preliminary conclusions show that there is overall agreement for spatial distribution, though GOES assigns CTH higher than MISR and MODIS. GOES and MODIS are picking up high-level clouds while MISR does not detect most of those in multilayer conditions.

Future work will include assessing whether M4 and/or CF/DF cameras improve MISR CTH retrieval for multilayer conditions; work on understanding the MODIS CTH low bias; ongoing comparisons at Chilbolton and SGP (and expanding to TWP and NSA); using radiosonde data where available during overpasses; and expanding MISR-MODIS CTH inter-comparisons to the whole CLOUDMAP2 area and employing radiosondes for CTH truth.

### **Seasonal Variability Studies Across the Amazon Basin with MODIS Vegetation Indices MOD 13**

Dr. Alfredo Huete began by saying that validation focuses mostly on the output, or uses, of the product, like phenology, change detection, and biophysical models. The two vegetation indices are NDVI and EVI, but they are also using SAVI. They want a long-term stable time series that would be useful for models of climate and El Nino studies.

The team performed various field experiments in the central portion of South America that included extremely dry and wet climates, and looked at variations over 2 years of measurements between dry and wet seasons at different test sites. Their actual measurements are

matching EVI and NDVI values generated by canopy radiative transfer models. The team found that MODIS is useful in characterizing the spatial and temporal dynamics of the Amazon Basin. Multi-temporal profiles of the MODIS data revealed well-defined seasonal patterns in the cerrado region with decreasing dry-wet season patterns in the transitional areas near Santana do Araguaia. Seasonality was observed to a small and uncertain extent at the Tapajos National Forest site, however it was unclear whether this was associated with seasonal changes in forest leaf area or temporal changes in the understory vegetation. They also found MODIS VI seasonal patterns to significantly vary in land-converted areas. The algorithm seems to work well, and there is a CD that explains their quality assurance process that will help users to determine accuracy requirements. The largest uncertainties seem to be induced by clouds, cloud shadows, and BRDF. Dr. Huete also mentioned some snow problems - NDVI underestimates snow color while EVI overestimates. The group's intermediate solution is to switch to SAVI when they get a snow flag; however, this forces them to sacrifice aerosol quality.

Dr. Huete concluded that the VI product is still provisionally validated from radiometric, seasonal, inter-annual, and biophysical perspectives. There are still problems with BRDF, clouds, cloud shadow, topography, and snow. Dr. Huete noted that the Vegetation Index product accuracy varies with QA (which allows a user to filter out lower quality data).

**Status of the MODIS Land-Surface Temperature/Emissivity Product: New Validations and Improvements – Zhengming Wan and Simon Hook**

Dr. Simon Hook began the presentation by providing results from the Lake Tahoe CA/NV validation site. He said that they deployed 4 buoys on Lake Tahoe that took measurements every 2 minutes.

The validation results for the calibrated radiance at sensor data (MOD02) in the clear window MODIS thermal infrared channels were very good. There was no bias in the MODIS clear window thermal infrared radiances since launch. A similar comparison was performed with ASTER and the results indicated a small bias. The scatter in the MODIS compared to ASTER validation values was a little larger, but may be due to differences in viewing area. For validating surface temperature measurements, there is a cloud mask issue, and they have to reprocess to a 66% confidence level so that water sites (like Lake Tahoe) are not always identified as “not clear” by the MODIS cloud detection algorithm. There was a small bias in the MODIS land surface temperature product (MOD11). They validated 15 ASTER scenes and 31 MODIS scenes.

Dr. Zhengming Wan said that the MODIS LST validation indicated the algorithm was performing well. He showed the seasonal variation in the day and night lake surface temperatures of Lake Tahoe at an accuracy better than 0.6K (the average error is 0.3K)

with the MODIS LST product compared to Simon Hook's in situ measurement data. The MODIS LST group are working on LST validation in wet atmospheric conditions in Mississippi. Five TIR radiometers were deployed in a soybean field, three in a rice field. The field measurements will be continued in order to validate the MODIS LST product in the fall of 2002. MAS day/night flights around the Terra and Aqua overpass times were scheduled for early August to estimate the calibration of Aqua MODIS TIR bands and to validate the Aqua MODIS LST product.

Six new improvements have been made for the MODIS LST code. Lake pixels in clear-sky at a 66% confidence level and higher defined by the MODIS cloud mask product (MOD35) will be processed. The MODIS BRDF product (MOD43B1C) will be used as input. The range of viewing zenith angles has been separated into five sub-ranges. The code will process data from odd and even days in parallel to double the production rate. The Terra and Aqua MODIS data may be used jointly in the day/night LST algorithm for better spatial and angular coverage. Finally, a split-window method was incorporated into the day/night LST algorithm to ensure that split-window algorithms can use the retrieved emissivities.

Dr. Wan showed some good quality early Aqua MODIS TIR data with small NEdT values and reduced calibration bias in Bands 20 and 22. The LSTs retrieved from Terra and Aqua MODIS data show the expected diurnal variation. The retrieved surface emissivities in the Sahara are close to the measured values of sand samples, and the retrieved emissivities in Caspian Sea are close to the theoretical values for seawater.

### **MODIS LAI and FPAR Products: An Update on Status and Validation**

Dr. Ranga Myneni began by announcing that the team did an outreach project in Missoula, MT. MODLand wants to reach out to the community with different suites of products, and at this particular workshop they used the MODIS vegetation variables suite. The workshop was tremendously successful - 140 registered for the meeting. Steve Running was the host, and about 110 of the attendees were new users. The workshop was almost 3 days long, with most talks about two hours long, and there was an afternoon hands-on session which users were very happy with.

Dr. Myneni gave a number of highlights of the MODIS LAI/FPAR project, including publishing over 20 articles, developing the LAI/FPAR algorithm, and producing two years of LAI and FPAR data sets. He explained that the data has been made available on CDs and can also be downloaded from an ftp site <ftp://crsa.bu.edu/pub/rmyneni/myneniprducts/>. The CD includes a monthly summary of the standard 8-day products at 1 and 4 km resolutions. There is 4km data available, and the read-me file points to the ftp site for 1km files. The CD also includes some tools to help read and manipulate the data and numbers.

Dr. Myneni continued that validation started from the first MODIS launch. They have plans for campaigns through July of 2004 across a range of biology types – at least one per continent from the north to south latitudes. Dr. Myneni gave descriptions of a field validation campaign in Sweden and another in the Safari. He showed how they compared ground measurements to MODIS/LAI data to accomplish validation. Among the conclusions drawn from the field experiments was that the first-year MODIS LAI algorithm correctly accommodates structural and phenological variability in semi-arid woodlands and savannas, and is accurate to within the uncertainty of the validation approach. In conclusion, Dr. Myneni said that the MODIS LAI product is validated.

### **The MODIS BRDF/Albedo Product: Evaluation, Validation, and Applications**

Dr. Crystal Schaaf began by describing the MODIS BRDF/Albedo Product. The BRDF model parameters describe the surface anisotropy. Albedo and surface reflectance can then be computed at any desired view and illumination geometry. The bihemispherical albedo (white-sky) and directional-hemispherical albedo (black-sky) at local solar noon can also be computed. Actual albedos can be estimated by interpolating the diffuse and direct beam albedos as a function of diffuse skylight. Nadir-Adjusted Surface Reflectances (NBARs) are corrected to a common nadir viewing geometry. The product provides both 1km and .25-degree products. They are very careful about quality assurance and the stability of their products. Dr. Schaaf explained that for quality assurance the MOD43B 1km ISG products contain two 32 bit-packed words coding for data quality as well as other useful information. They are very happy with the current status of albedo retrievals.

Dr. Schaaf showed how Aqua MODIS data enhances Terra MODIS NBAR data and said that it is exciting because they can be coupled together as soon as the Aqua MODIS calibration is stable. When they add Aqua MODIS observations to those of the Terra instrument, the percentage of high quality results increases significantly.

Dr. Schaaf said that validation is ongoing. She showed MODIS, SURFRAD, and CERES comparisons, and indicated that everything seems to be in synch. Team evaluation has focused on the temporal stability and consistency of the products, on the variability by land cover, and on the MOD43B Quality Assurance Flags. MODIS-Aqua directional reflectances will be added to MODIS-Terra values to increase sampling and improve the quality of retrieved BRDFs. Reprocessed 1km MOD43B BRDF/Albedo products are available from November 2000 onward (in ISG in 10° tiles). The MOD43C CMG 1/4-degree products are available from July 2001 onward. Dr. Schaaf also noted that there are a number of collaboration efforts underway, and two papers on desert and snow/non-snow albedos of land cover classes were recently published in GRL and Nature.

Dr. Schaaf said that they are working on wider utilization of MODIS BRDF/Albedo Standard Products and are very focused on community research and outreach. In conclusion, she said that evaluations indicate that the MOD43B algorithms have performed well throughout 2000, 2001 and into 2002. The reprocessed Terra albedo measurements appear temporally stable and consistent, and the indications are that the QA flags are appropriate. Initial validations and comparisons over sites in the US are encouraging with errors of less than 10% in the growing season, and based on these analyses, MOD43B products have been upgraded to a status of "Validated (level 1)". Further increases in quality are expected with the addition of Aqua surface reflectances.

### **The MODIS Land Cover/Land Dynamics Product: Status and Validation**

Dr. Alan Strahler explained that to get the MOD12Q1 product, they use MODIS data (one year of 16-day NBARs and 16-day EVIs), training data (from >1,500 training sites delineated from hi-resolution satellite imagery), and a decision tree classifier. Dr. Strahler explained that they also use a post-classification process of using prior probabilities to remove biases, resolve confusions, increase accuracy, and to fill in cloud-cover pixels from earlier maps in order to produce a consistent product and classify cereal and broadleaf crops.

Dr. Strahler said that in June of 2001 they produced a provisional Land Cover Product, and in June 2002 they released a Consistent Year Land Cover Product. He showed a number of slides that illustrated how they have improved land type classification, vegetation type classification, confidence levels, and distinguishing vegetation types from one another.

Dr. Strahler said that they are trying multiple validation approaches. For level 1, they do comparisons with existing data sources. For level 2, they do quantitative studies of output and training data, for example, using per pixel confidence statistics. For level 3, they use sample-based statistical studies, such as random stratified sampling according to proper statistical principles. They also do cross-validation with training sites. Their accuracy levels for the Consistent Year product are 78.6% before priors, 71% after priors, and 84% after priors in the first two classes. MODIS accuracies overall are within the 70-80% range, with most mistakes occurring between similar classes. Dr. Strahler cautioned that land cover change should NOT be inferred from comparing successive land cover maps.

In closing, Dr. Strahler announced that they will soon release a Land Cover Dynamics Product that will quantify inter-annual change and phenology, and showed a number of images from the product.

### **Rapid Response System**

Dr. Jacques Descloitres emphasized that rapid response is critical to fire detection and press release imagery. He explained that the approach of the MODIS Rapid Response Project is to develop a

rapid and flexible processing and distribution user-driven system as an alternative to the ECS system for near-real-time applications; to provide enhanced PR and outreach for some of MODIS' unique capabilities; to generate value-added science-quality products to augment the MODIS standard products; to reuse existing software, hardware, and expertise; and to develop applications partnerships with other agencies.

The system's characteristics include using the existing "bent pipe" feed mechanism from NOAA's NRT System used to generate weather products, using IMAPP software (DAAC processing code modified for Direct Broadcast applications) to produce MODIS level-1 products. The system does not need real-time ancillary data, nor does it need an operator - the processing system is fully automated. Lastly, the system can produce corrected reflectance and active fire locations within two to five hours of data acquisition and automatically send that data to the Rapid Response distribution site and partners.

Product distribution uses a number of approaches. RGB imagery with Active Fire overlay is archived and distributed to the public via the Rapid Response System at NASA/GSFC, and near-real-time imagery can be accessed at

<http://rapidfire.sci.gsfc.nasa.gov/realtime/>. Selected handcrafted imagery is available at <http://rapidfire.sci.gsfc.nasa.gov/gallery/>. The online archive has no ordering interface, and the entire Rapid Response site uses a straightforward point-and-click interface. Application-specific products are distributed by partners, and the Rapid Response System has a privileged relationship with selected science image publishers to increase product visibility, such as the Earth Observatory, Visible Earth, the MODIS homepage, NASA's Public Affairs Office, and the Science Visualization Studio.

The MODIS Rapid Response System started generating products in April 2001, and the first field implementation of the Rapid Response System in a Direct Broadcast environment was prototyped in December of 2001 with the USDA Forest Service. They also make ongoing efforts to make Rapid Response processing software available to Direct Broadcast users via the Direct Readout Lab at NASA/GSFC, and the active fire detection code was distributed in April of 2002. Dr. Descloitres said that they've made a lot of progress recently, including substantially reducing production gaps thanks to improved input feed from the NOAA NRT System since June 2002 (less than 1% data loss); implementing version 4 of the active fire algorithm, implementing a Rapid Response Vegetation Index product, sending over 1100+ images to the Visible Earth database, and beginning working on the transition to NOAA NRT system. The popularity of the system is growing as well - there were 5675 different visitors and 75000 downloaded images in June 2002 alone. The Aqua MODIS first light images have been processed in the Rapid Response System, but there are still some geolocation issues to solve.

Lastly, Dr. Descloitres said that additional information is available at the following sites: <http://rapidfire.sci.gsfc.nasa.gov/> and <http://rapidresponse.umd.edu/>.

## **Land Discipline Summary**

Dr. Justice ended the Land portion of the plenary sessions. His listed the current emphases for the Land Group as being Aqua calibration and product quality assurance; Land product outreach, including user community feedback; product validation; and preparing for Collection 4.

In the area of outreach, Dr. Justice noted that the RSE MODLAND Special Edition (early Validation results) has been submitted and is expected to be published by the end of the year. The first three in the sequence of Land Product Outreach Workshops have been held, were well received by the attendees, and the team is receiving much useful feedback. The new IDS data product initiative is aimed at meeting the needs of the modeling community. Part of the outreach activity is aimed at helping established AVHRR users to become aware of new MODIS capabilities. The Land Team is concerned that the advances achieved by MODIS for land monitoring are retained by the planned NPP VIIRS instrument.

Based on user-feedback, the land group is proposing a modification of the ISIN Projection to make it more compatible with COTS reprojection software. The proposal to move to a SIN projection will not significantly impact the data production schedule and will take effect in Collection 4. The land group reiterated that work is needed on the provision of improved tools and user service that will enable science users to better manage and analyze MODIS data. The group encouraged ESDIS to redouble its efforts to work with image processing vendors to include MODIS processing capabilities. MODIS data usage continues to be evaluated by the DAACs. It was proposed that the EDC DAAC compile a list of voluntary MODIS land data users so that a closer connection can be made between the science team and the user community to ensure that user needs are better understood.

The Land/Water Mask needs to be improved and it was suggested that the SRTM may be an important source of data. It was suggested that the NASA DEM Working Group might be resurrected, now that the SRTM data are starting to be made available. The next steps for the IDS data sets are being determined and the relationship to the CMGs is being evaluated. The development of MODIS time series studies is awaiting the first major Land reprocessing starting October of 2002.

Validation is in progress and includes efforts to internationalize the validation effort through the CEOS (Committee on Earth Observation Satellites) Land Product Validation Working Group and the Global Observation of Forest Cover / Global Observation of Landcover Dynamics (GOFC/GOLD) regional networks. There is an effort underway to expand the EOS Validation Test Sites to become the

CEOS Validation Test Sites with involvement of other space agencies that are providing similar land products to MODIS.

Currently, EOS identifies Beta (the code is running with known issues), Provisional (known problems are identified, product intercomparison and validation are underway) and Validated Data (product accuracy has been determined). The Land group proposed three distinct stages of validation that reflect the extent of validation and level of effort needed:

*Stage 1 Validation* – Product accuracy has been estimated using a small number of independent measurements from selected locations and time periods, results are published in the peer-reviewed literature.

*Stage 2 Validation* – Product accuracy has been assessed by a number of independent measurements, at a number of locations or times representative of the range of conditions portrayed by the product e.g. EOS Land Validation Core Sites, Fluxnet sites, Aeronet sites. Results are published in the peer-reviewed literature.

*Stage 3 Validation* - Product accuracy has been assessed by independent measurements in a systematic and statistically robust way representing global conditions e.g. IGBP DISCover Project. The results are published in peer-reviewed literature.

The Land Group believes that validation needs to become a mainstream activity for NASA and those agencies providing derived satellite data products. It is also important that validation data be made available to the broader community. It is hoped that the validation approaches developed for MODIS will be adopted for products to be generated from the NPP VIIRS.

Overall, Dr. Justice expressed the feeling that MODIS is an outstanding instrument with excellent data products available for land science. The data from Aqua MODIS, though still new, look extremely promising. Data production overall has stabilized, although the team is keeping an eye on how much of an impact the ramp-up of Aqua data processing will have. He indicated that the attention of the Science Team is shifting to critical issues of data distribution and data use, although this was not originally envisioned as a major focus role for the STM. User awareness of the products is increasing, though it needs to be broadened through continued outreach efforts and facilitated by the provision of data analysis tools. Responsiveness to user needs is important.

## **Session Discussion / Panel on Accessing MODIS Data Products**

Salomonson introduced the Session Discussion / Panel on Accessing MODIS Data products. He stated that reaching the potential for utilization of MODIS products by the scientific and applications communities depends on four factors. The first (1) factor is to have a well-performing, well-characterized instrument leading to carefully calibrated radiance (Level 1) data. The second (2) factor is the development of scientifically valid, geophysical (level 2 and above) products derived from carefully constructed and validated algorithms developed by the MODIS Science Team. The third (3) factor is the development and operation of an adequate data processing capability leading to careful processing and reprocessing of the MODIS products. Salomonson said that this is necessary not only to provide optimized observations utilizing the full power of the instrument, but also time series over the lifetime of the mission that allow geophysical trends to be established eventually leading to new scientific insights. The fourth (4) factor is the provision of capabilities that allow the broad Earth science and applications community to readily and efficiently access the MODIS products.

Given the above discussion regarding successful use of the MODIS capabilities, Salomonson said that the MODIS Science Team feels that factors 1-3 have largely been and are continuing to be accomplished. The major challenge at this time is to improve the access to MODIS products. This is a particular challenge for the MODIS situation because of the breadth of capability (i.e., number of bands, 3 different spatial resolutions, 12-bit quantization) and the attendant volume and complexity of the MODIS data products. Salomonson said that while considerable progress has and is being made on these issues, more needs to be done.

### **Data Processing Tools**

Dr. Graves started the panel presentations by describing developments in subsetting, data mining, and Earth Science Markup Language (ESML) tools for scientists. She first presented an overview of the ESDIS system with highlights on recent developments and noted that a demonstration was ongoing of newly developed software tools. These developments fall into four categories:

*Data Usability* – the big problem among the science community is how to use the new remote sensing data. ESDIS developed ESML, an adaptation of HTML, to enhance the data's usability.

*Science Data Preprocessing* – tools for subsetting and browsing.

*Science Data Analysis* – including data mining and algorithm development.

*Mission/Project/Field Campaign Coordination – including electronic collaboration.*

Regarding ESML, Graves said that the concept is to define something once and use it many times. The heterogeneity of data formats has created a huge usability problem, but with the development of ESML, the ESDIS can create an ESML file for each data set that serves as a description/metadata file and provides a structural description as well as semantic and syntactic data files. ESML is a machine-readable and interpretable representation of the structure and content of any data file, regardless of format.

Graves listed the tools currently available (accessible via <http://esml.itsc.uah>) and cited examples of comparative studies using MODIS and MISR data for correlation with CERES short wave flux data. Regarding subsetting, Graves said that there are many tools (accessible via <http://subset.org>), including an available toolbox of subsetters. She noted that her organization has also developed and made available a number of subsetting tools.

Graves announced that the HDF-EOS Web-based (HEW) subsetter is now complete and available, and noted that it is possible to customize a front end and set up subset centers. They are developing tools for stitching data granules, and the integration of HEW with ECS is in progress. They are also planning on making subsetting into a web service. Salomonson asked whether it is possible to specify according to band and geographic locations, and Graves said yes, it is possible. Concerning data mining, Graves said that the task is to discover interesting patterns and anomalies and to extract novel information. Data mining is only as useful as the scientist using it makes it. Scientists must be able to know when they've found something of value. She concluded that it is an iterative process.

## **User Services Experiences and Activities**

### **GSFC DAAC**

Jim Koziana began by saying that the MODIS mission is unknown to potential users at a surprisingly large level. In the area of data discovery, access, and delivery, Koziana said that current issues include data maturity, enhanced data previews, the look and feel of the web interface, unknown order status, multiple product ordering, and the quality of archived data (duplicates and missing data). As for data usability, he identified an issue with getting MODIS data into a GIS (i.e., GEOTIFF) or other simple format. There are too many parameters in a single file, and file sizes are too big. There are also no simple tools available for using data. Koziana identified the most popular MODIS data products, emphasizing their use in regional and global studies. One person in the audience suggested it would be interesting to see how orders from team members compare to orders from all other users.

Koziana reported on the response of remote sensing data users from IGARSS 2002. Twenty-four percent of respondents said that they

didn't know anything about MODIS data. Thirty-two percent said they haven't used it, but see its improvement over older RS data and plan to use it in the future. Eighteen percent said that they work with higher resolution data than MODIS provides and require real-time data. Twenty-two percent said that they are very satisfied with their acquisition of MODIS data, and four percent expressed general dissatisfaction. Koziana said that conclusions from IGARSS show that small data volume users are accessing MODIS data at a healthy pace, and that MODIS data are relatively unknown outside the IWG community. Koziana explained that there is a natural lag between the availability of new data sets and end users, so growth should occur as more information about MODIS products become available and concomitant research and applications needs or opportunities develop. He mentioned that TRMM data distribution did not see a marked increase until about 20 months after TRMM launch. In conclusion, Koziana listed the GDAAC's future directions.

### **Land Processes DAAC**

John Dwyer reported that the Land Processes (LP) DAAC has a user support model that includes the use of a web-based system to log customer contacts and responses, uses a "consultation tree", publishes FAQs, and is capable of generating summary reports. He reported that the user community recognizes that the turnaround time from data acquisition to product availability is getting better, and highlighted positive user community response to the increasing availability of MODIS 250 m products. The LP DAAC provides "1-page" fact sheets on their web site that provide general descriptions of the products, format and data type specifications, valid data ranges, scale factors, and explanations of the QC-bits. The more common inquiries received from users regarding data set characteristics include product formats, metadata, questions about data and information from other sites, and projection and grid characteristics. Dwyer noted that most ASTER data are requested on media (CD and DVDs), whereas MODIS data are mostly distributed via ftp. Regarding software tools, Dwyer said that current issues include file formats that are incompatible with COTS tools, and COTS deficiencies in using geolocation and quality control bits.

In summary, Dwyer said that he is seeing an overall positive response from the community of MODIS Land data users. The user community is alive and growing. The LP DAAC is pursuing a CPU upgrade to the local EDG client, the implementation of data pools, and improving links to additional information and alternative data sources. Dwyer noted that the workshops conducted by the MODIS Land science team have been providing excellent feedback.

### **NSIDC DAAC**

Marilyn Kaminski reported that the NSIDC currently has eight snow and ice data products, and distribution numbers are going up rapidly. She said that this is a good sign of maturity of the products and that tools are becoming available. However, there are still problems. Kaminski said that the EDG is slow, cumbersome, and difficult to use. She said that a solution could include data pools to allow many

users to avoid the EDG. The NSIDC is developing scripts to enter queries directly that include ESDT, location, start time, and stop time information. Another solution could be an improved EDG tutorial.

Kaminski also reported that the ISIN projection is difficult to use. Suggested solutions included the NSIDC providing the EDC with code fixes for the MRT, offering workshops, offering an improved MODIS image gallery, improving the HDF-EOS support pages, and better advertisement of NSIDC-developed tools for data manipulation. Kaminski acknowledged that the EDG is problematic for casual users, but people do get better at using it over time.

## **User Community Experiences and Suggestions**

### **A MODIS Oceans User Experience**

Tim Moore reported that he has been working with RS data for the past 10 years. He's also been using SeaWiFS data from the DAACs, and most recently he has started using MODIS data. Moore said that, given his experience with it so far, he would give it a "B" grade.

Moore grouped users into three levels: Novice (no HDF, MODIS or SeaWiFS experience), Average (some HDF, some SeaWiFS, no MODIS), and Expert (HDF and MODIS experience). He said that most users fall into the novice and average levels.

He indicated that the overall MODIS web structure is complicated, disjointed and tangled, resulting in an overall "C+" grade. There are many duplicate pages across different groups (i.e., MODIS, GDAAC and MODAPS pages) and FAQs are needed up front on the MODIS home page. Some good pages are buried too deep, i.e. <http://daac.gsfc.nasa.gov/MODIS/software.shtml>. He noted that most of the Oceans community is already familiar with the GDAAC from SeaWiFS experience and will prefer the GDAAC over the EDG for data access, but many others are lacking that frame of reference. Given this, no specific comments on the EDG, but overall it is clumsy, confusing, and discouraging to use.

Some specific recommendations for the GDAAC however were made. Overall, Moore said that the DAAC got a "B+", and could improve a few issues. They should allow for temporal searches greater than 8 days, they should build in links to all ocean products and geo files, they should provide a true-color browse for L2 granules, and he recommended removing the long list of disclaimers from their prominent level on the final page before submitting an order.

### **A MODIS Land User Experience**

Dorothy Hall began by noting some good points about the DAAC. She said that data center unplanned downtime has been much less than it was six months ago, data is available just a few days after acquisition, and the data center personnel are very helpful. She noted that she often gets notifications that her requested MODIS products have been staged for ftp within a few minutes after ordering

them. She also noted that the NSIDC will put daily CMG maps up on their site as jpg files for easy browsing prior to order, and browse products will be implemented this fall. Hall continued that the EDG has a steep learning curve, but once mastered, it's easy. She noted a number of excellent features, including showing where the study area is located. Hall said that the browse problem is currently being addressed.

Hall then turned to some of the negatives. She said that there is a general lack of browse products for most of the products she searches for, and the system is very slow every time she "turns" a page. Hall said that the granules should be numbered when they are listed, which is very important for large orders (more than 10 granules). She highlighted too much wasted space on the granule listing page that requires a lot of scrolling and mouse clicking that should be avoided. It is also awkward at times, especially when you want to select your data set from among the hundreds of choices and when granules are displayed.

Hall said that in regards to HDF, ENVI makes it easy to read HDF files, but it is expensive and a lot of people, especially students, don't have access to it. Many people prefer flat binary files. As for the MODIS reprojection tool, users must register for it. Hall said that it took her a day to register, but it took a week for a student with whom she spoke, and she wasn't certain why.

In conclusion, Hall said that the data centers have made good progress in data distribution and reducing unplanned downtime. The EDG is slow and awkward, but becomes easy with experience. Free tools should be available right away, and browses should be produced for each product when possible.

## **A MODIS Atmospheres User Experience**

Bill Ridgway focused on the process of getting the desired files from the archive to the desktop, highlighting the complexity of choices that the user must make in the process.

In the area of selection, Ridgway said that the EDG and "no-frills" tools have perhaps 50% of the desired functionality. The search and wait interface is not adequate for serious research. Geographic searches include excessive near misses, and the MODIS product packaging remains a big issue. As for staging, Ridgway said that it can take anywhere from five minutes to 48 hours. He acknowledged that the number of failures have come down a lot in the past year, and also noted that the demand on system resources limits orders. In the area of delivery, Ridgway said that the ftp pulls are most reliable, and product volume is probably the greatest obstacle. As for help, Ridgway said that better tools, better examples, and better images are still needed.

Ridgway then turned to selection roadblocks. For the novice, Ridgway pointed out the maze of navigating ESDT and collection numbers. The products are packaged with too many parameters, there are no useful browse images, and selecting data with the right

time and or location is problematic. For the repeated/experienced user, Ridgway highlighted order size limits, the “no-frills” GDAAC interface can’t always do what he needs, the EDG interface is torturous (though has useful functionality), and both are painful for repetitive ordering (both should allow for profile repeat orders).

Ridgway suggested streamlining the EDG and “no-frills” interface for repeat customers, pointing out that they already know what they want and just need an easy way to get it. He also suggested a data pool with an ftp interface for machine data acquisition, a geographical search tool that really works, and easy ordering of many products for a five-minute granule.

## **ESDIS System Developments and Plans**

### **EOSDIS Plans to Improve Data Product Access and Delivery**

Mike Moore agreed that there are significant issues on the front end and from the user’s perspective that must be immediately addressed and resolved. He said that he will work to form a team of MODIS, MISR, and ASTER users to identify, prioritize, and decide how to implement solutions to those issues.

Moore said that the EOSDIS has been working with the Data Access Working Group (DAWG) to identify and prioritize needed changes as well as addressing many items through a Synergy program. They expect to receive Science Working Group for Data (SWGd) distribution recommendations soon, and will address them as funds become available based on SWGD priorities. They are implementing SWGD ingest and archive recommendations based on currently available funds with special emphasis on archiving L1A subsets. Moore said that they are enhancing the Data Pools to provide more on-line data and data services, and noted that an initial Data Pool is operational at the GSFC DAAC. They are enhancing the HDF toolset (HDF EOS to GeoTiff or “HEG”) to aid in the use of retrieved data, and are integrating the UAH HEW subsetter into the ECS. Moore also listed the DAWG results to date.

Moore listed the Data Pool CY ’02 enhancements/capabilities to be delivered by December 2002. They will deliver population via search and script-based ingest; interfaces to external ECHO and EDG search engines; personalized data views, bookmarks, and data themes; and access via OpenGIS interfaces. They will deliver data access services via an HDF toolset (HEG); compression of data on distribution; and expanded capacity and throughput (due in August 2002). The capacity and throughput will include 2tb for the NSIDC; 44tb for the EDC with on-line ASTER L1B in GeoTIFF; 25tb for LaRC; and 63tb for GSFC, including on-line MODIS L1B data to smooth flow to MODAPS. Lastly, EOSDIS will provide management of NEPSTER direct broadcast and Rapid Response data for MODIS as well as consistency checking tools.